May 2025
M.Sc.
Fourth Semester
DISCIPLINE SPECIFIC ELECTIVE – 03
PHYSICS
Course Code: MPHD 4.11 (A)
(Atmospheric Physics)

Total Mark: 70 *Pass Mark: 28*
Time: 3 hours

Answer five *questions, taking* one *from each unit.*

UNIT–I

1. (a) Consider a gas with an initial pressure (P_1), volume (V_1), and temperature (T_1) increased to pressure (P_2) and volume (V_2) at constant temperature (T_1). Apply the relevant gas law to show that adiabatic process is an isentropic process. 7
   (b) Establish the Poisson's equation for pressure and temperature and show that potential temperature is a conservative property. 7

2. (a) Consider that there is an exponential dependence with height of 7995 m such that the small vertical variation of the gravitational force with height is neglected. Compute the approximate height above sea level at which the mass of the atmosphere lies above and the other half lie below. 4
   (b) Calculate the gas constant for a gas mixture of 300 litre containing 6.7 mol of hydrogen gas at the freezing point of water with a partial pressure of 0.50 atm and 3.3 mol of oxygen gas. Use the calculated value of the gas constant to estimate the total pressure of the mixture. 4
   (c) The mean temperature of the tropic at the mean sea level is 300 K while the tropopause temperature is around 353 K. Estimate the mean lapse rate within the tropical troposphere in terms of degree centigrade. 3
   (d) Calculate the vapour pressure for air containing water vapour with a mixing ratio of 5.49 g kg^{-1}. 3

UNIT–II

3. (a) Highlight the growth of cloud droplet by condensation along with a graphical representation for the relationship between relative humidity, super saturation, and droplet radius for curved surface undergoing curvature effect. 7

   (b) Consider a non-volatile solute added to a pure solvent to show that the solution effect dominates when the radius is small for the Köhler curve. 7

4. (a) Justify the formation and growth of cloud droplets by addressing various process. 5

   (b) Highlight with relevant formula to explain the nucleation of liquid water in water vapour. 5

   (c) An air parcel for a sounding is found to have the level of free convection and equilibrium as 750 and 187.5 hPa respectively. Calculate the CAPE if, within the layer between those levels the reference air parcel is on average 10 degree Celsius warmer than the environmental air at the same level.
   (Gas constant = 287J K^{-1} kg^{-1}) 4

UNIT–III

5. (a) Consider an infinitesimal volume element of air with a pressure (P_0) centred at the centre of the element. Show that force is directly proportional to the gradient of the pressure and not to the pressure itself. 7

   (b) Derive the equation of continuity in Eulerian form. 7

6. (a) Write a short note on the Rossby number. 3

   (b) A layer of unsaturated air flows over mountainous terrain in which the ridges are 9 km apart in the direction of the flow. The lapse rate is 5°C km^{-1} and the temperature is 27°C. For what value of the wind speed (U) will the period of the orographic forcing match the period of a buoyancy oscillation. 3

   (c) The zonally averaged zonal wind of 20 m s^{-1} during the winter along 40°N is eastward while the zonally averaged meridional wind component of 30 cm-s^{-1} is southward at 300 hPa (10 km) level. Compute the vorticity and divergence averaged over the polar cap region poleward of 40°N. 4

(d) Estimate the amplitude of the dynamically-induced radial pressure gradient when air of density 1 kg m^{-3} at cloud base in a supercell updraft is observed to be in solid body rotation out to a radius of 2100 m with a period of 700 seconds. 4

UNIT–IV

7. (a) What is barotropic instability? Show that the absolute vorticity must be a constant somewhere in the flow for barotropic instability. 3+4=7

   (b) Derive the governing equations of the planetary boundary layer using Boussinesq approximation. 7

8. (a) What is perturbation theory? Derive the condition that the perturbation field is very small compared to the static field in linear perturbation theory. 2+4=6

   (b) Estimate the turbulent transfer coefficient for momentum if the effective depth of the Ekman is 1404 m with a Coriolis parameter of 10^{-4} s^{-1}. 4

   (c) The potential temperature is 290 K and increases at 0.01 K per metre at a certain level in the lower troposphere, The east-west and north-south wind components increase with height at rates of 0.02 and 0.01 per second, respectively. Calculate the Richardson number and state whether the flow is dynamically stable or likely to become turbulent. 4

UNIT–V

9. (a) Show that the potential vorticity flux is directly proportional to the divergence of the Eliassen-palm flux vector. 7

   (b) Write a note on each of the following. 3½×2=7

   (i) Atmospheric circulation

   (ii) Eddy transport of momentum and energy

10. (a) Highlight with mathematical background about the sigma coordinates. 5

    (b) What are climate models? Write the basic equation in climate models. 2+3=5

    (c) Explain briefly data assimilation in numerical weather prediction model. 4
